The Influence of Atmosphere-Ocean Interaction on MJO Development and Propagation

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LONG-TERM GOALS

The long-term goal of this project is to understand the role of the atmosphere-ocean interaction processes in the initiation, maintenance and propagation of Madden Julian Oscillation (MJO). Better understanding of the atmosphere/ocean feedbacks in the Tropics will allow formulating more accurate parameterizations of the air-sea interface in the forecasting models. It will contribute to improved predictability of the MJO and other coupled phenomena on various special and temporal scales.

OBJECTIVE

The objective of this research is to examine how the air sea interaction influences the atmospheric and oceanic processes involved in MJO initiation and propagation. The impact of surface fluxes on ocean equatorial waves and the development of atmospheric convection as well as the role of atmospheric convection in modifying the upper ocean are studied.

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APPROACH

The three ways coupled atmosphere-ocean-wave model (two-way interactive between COAMPS®[1] and NCOM; one way interactive with SWAN) is used to examine air-sea interaction in the Indian Ocean during the active and inactive phase of MJO. The model is used for process studies that aim to evaluate atmosphere-ocean feedbacks and their influence on MJO development, and for forecasting of air sea interaction in the Indian Ocean basin and its influence on MJO. The impact of various physical processes and their parameterizations on simulation and predictability of MJO is examined.

The integral part of this project was the participation of the 2011 field experiment. We provided forecasting support during the field phase and observation data obtained from the experiment are used to constraint/evaluate modeling results and process studies. The field phase of this project is associated with DYNAMO, which is the US contribution to the interactional experiment CINDY 2011.

WORK COMPLETED IN 2014

In the past year, we primarily worked on modeling studies dealing with:

1. The role of equatorial waves in MJO initiation
2. Impact on air/sea interaction on equatorial wave dynamics
3. The development of salinity lenses and their influence on ocean temperature
4. Extended run for DYNAMO with high vertical resolution NCOM

RESULTS

Summary of project results

The work funded under this project allowed us to update and clarify our understanding of the role of the air sea interaction in the MJO transition from the active to convective phase in the Indian Ocean. The synthesis of our findings in this respect is shown in Fig.1. Fig. 1 is based on the observations and model experiments of the November 2011 MJO – the strongest MJO episode observed during the DYNAMO. The previous conceptual model that was based on TOGA COARE observations (Flatau at al 1996; Shinoda 1997) stressed the role of the ocean cooling caused by MJO related surface fluxes. The DYNAMO observations and our modeling studies indicate the importance of other processes such a diurnal variability in the Upper Ocean and interaction between the MJO and equatorial waves.

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[2]COAMPS® is a registered trademark of the Naval Research Laboratory.

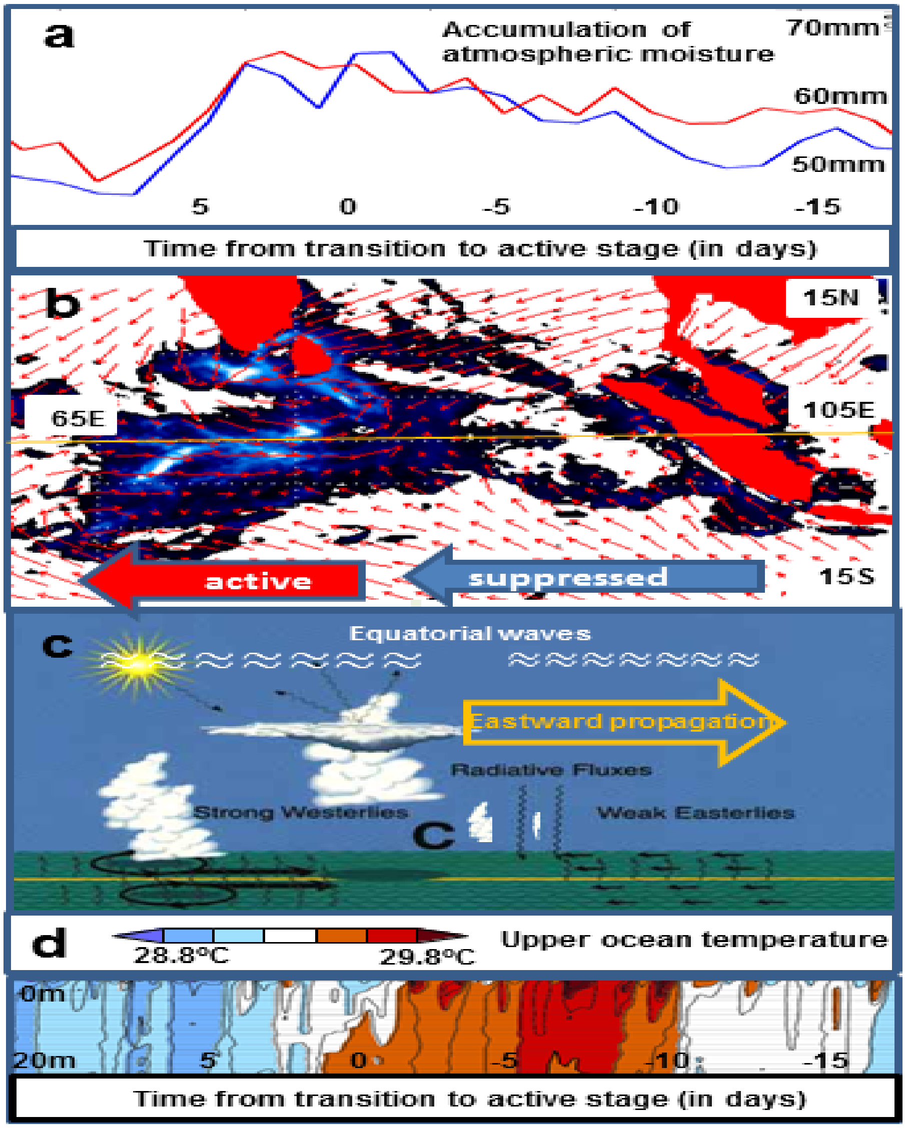

Figure 1: The synthesis of MJO transition from convectively suppressed to active phase based on DYNAMO observations, COAMPS simulations and conceptual model. The spatial patterns form the model and point observations from DYNAMO instruments are combined. a) The buildup of atmospheric moisture in the suppressed phase and the release during the active phase at 80E 0N, as observed in DYNAMO atmospheric soundings (courtesy of R. Johnson and P. Ciesielski) and COAMPS simulation adapted from Chen at al (2014),[3] b) the surface winds and precipitation from the COAMPS 11/23/2011 forecast of MJO. The area with strong winds and precipitation corresponds to the active phase, while the area to the east of the moving convection represents the suppressed phase. c) The conceptual model of air-sea interaction in MJO adapted from Flatau at al (1996).[4] d) The time series of the ocean temperature in the upper 20m of the ocean, measured by the Sea–Glider near the 80E 2N (courtesy of A. Matthews and D. Baranowski). The high temperatures and large diurnal cycle develop during the suppressed MJO phase. (From Flatau at al 2014

Fig 1a shows the moistening of the atmosphere before and during MJO, obtained from the DYNAMO soundings and COAMPS simulations. Our numerical experiments combined with DYNAMO observations suggest that the "moisture pumping' preceding the MJO development is influenced by the diurnal warming of SST in the clear areas ahead of the MJO convection, and by convectively coupled equatorial waves – especially mixed Rossby gravity waves (Chen at al 2014)

Fig. 1b illustrates the role of wave-wave interaction during the rapid development of MJO convection. In the event shown in this figure the eastward propagating Kelvin wave merged with the westward propagating MRG creating the westerly wind burst in the DYNAMO region, increase of surface fluxes and rapid strengthening of convection. This event and the role of tropical disturbances and air sea interaction in development of November 2011 MJO are discussed in (Hong at al 2014 and Flatau and al 2014). Fig 1c displays the conceptual model of the air-sea interaction in MJO (Flatau at al 1996) supplemented by DYNAMO findings – the impact of equatorial waves mentioned earlier and the upper ocean processes, as measured by the ocean sea glider, shown in Fig 1d. The development of the oceanic diurnal warm ahead of the area of active convection in the region of low winds and high solar fluxes is apparent (Mathews at al 2014). The high SSTs related to this diurnal warming impacts convection – especially in the suppressed MJO phase when the maximum rainfall in COAMPS lags the warmest diurnal SSTs by about 2 hours. In the active phase the afternoon rainfall maximum is observed in the areas of the weak winds at the leading edge of the Kelvin wave. The diurnal variability and its impact on convection during MJO are discussed in various papers supported by this project (Shinoda et al 2013, Chen at al 2014, Flatau at al 2014). The influence of convectively coupled atmospheric Kelvin waves on the diurnal variability of the upper ocean in MJO active as well as suppressed phase is discussed in Baranowski at al 2014.

While Figure 1 focuses on the local part of the MJO air-sea interaction, the ocean large scale response to DYNAMO MJO forcing and possible consequence for next MJO is discussed in Shinoda at al (2014), while the remote effects of MJO on precipitation over Philippines are shown in Pullen at al (2014).

Jensen et al (2014) discusses the development of equatorial jets and the impact of equatorial ocean wave dynamics on the heat storage.

Since the mesoscale coupled model was the main tool in the research in this project, we developed the MJO diagnostics geared toward limited area models (Flatau at al 2014).

The very important part of this project was the participation in the DYNAMO field phase. During the field phase (Sept, 2011-december 2011), the coupled COAMPS forecasts were run every day and were used to instrument placement planning and providing the background for the point observations in atmosphere and the ocean, and model intercomparisons.

2014 RESULTS

Air-sea interaction and moisture resurgence preceding MJO initiation

This investigation was a continuation of the last year research into the convection during the suppressed phase of MJO. Based on DYNAMO observations and COAMPS simulations we

formulated the conceptual model shown in Fig. 2.The model documents the primary structure of the 3-4 day cycle westward propagating MRG waves north of the equator and their hypothesized impact on the flow field, vapor, and cloud structure during the suppressed phase of the CINDY/DYNAMO MJO cycle, with deepest convective development occurring in regions of the MRG-induced maximum surface convergence and upper tropospheric divergence as noted to occur here and in previous studies of convectively coupled MRG waves.

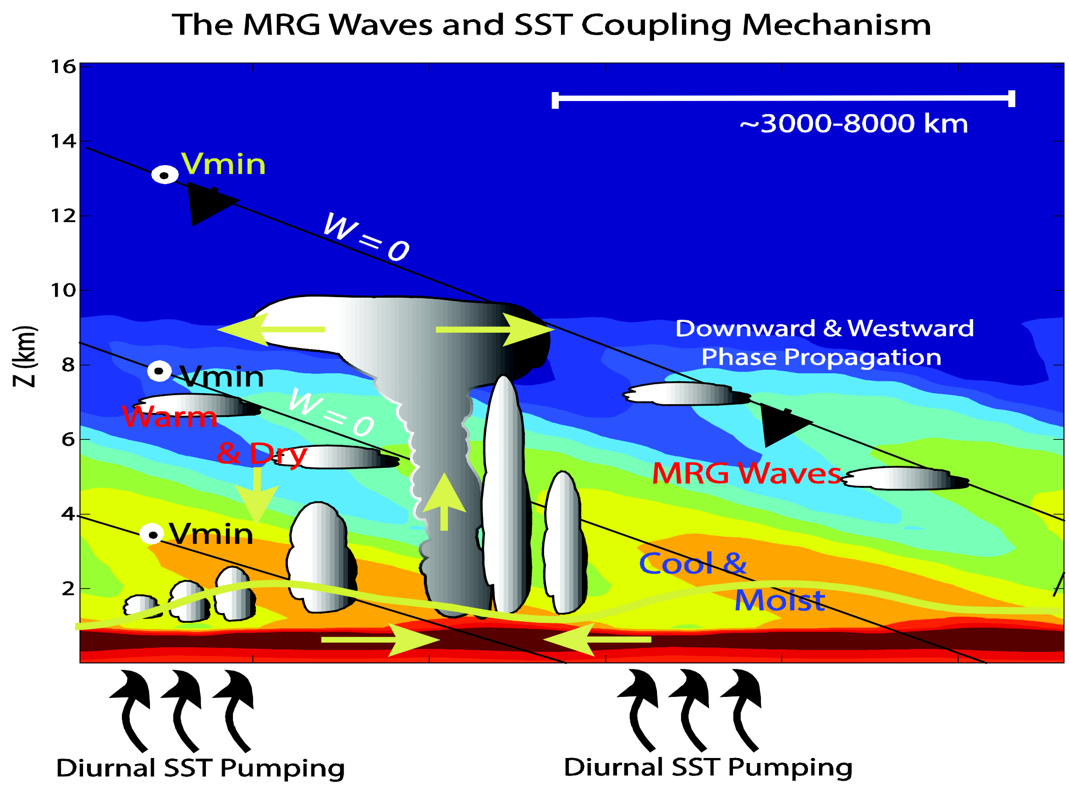

Figure 2. FIG. 21 A conceptual model summarizing the vapor structure of westward propagating MRG waves at a point north of the equator and their model-derived impact on the flow field, vapor, thermal field, and cloud structure during the suppressed phase (phase 5-8 of Wheeler and Handen MJO index) of the Indian Ocean CINDY/DYNAMO MJO cycle. The depicted MRG waves are suggested to have a horizontal wave length scale of ~3000 to 8000 km (Yasunaga et al., 2010) and a vertical wave length scale of approximately 6 km. The shading depicts sloping bands of higher (warmer colors) and lower (cooler coolers) relative humidity values that tilt westward with height and exhibit a downward phase propagation (denoted by the bold black arrow depicted in the plot). The black sloping solid lines depict the axis of the highest relative humidity and the phase lines where the vertical velocity is zero and the meridional flow component reaches in minimum value (denoted V_{min} and with arrow tips pointed out of the page). The bold horizontal yellow arrows denote the MRG-induced zonal flow perturbations while the vertically point arrows denote region of MRG-induced ascent and descent. Clouds are depicted by the white and gray shaded silhouettes and represent a transition from shallow cumulus to deep convective elements (not drawn to scale). Shallow layered cloud systems are depicted in regions of favorable ascent and/or in the banded zones of higher relative humidity values at various levels through the troposphere. The deepest convective clouds are depicted to arise in regions of strongest MRG-induced zonal surface convergence and upper level divergence. The bold curly black arrows below the abscissa denote increase surface fluxes from diurnally varying SST (From Chen at al 2014)

The impact of air sea interaction on MJO and tropical wave simulation in COAMPS.

We have shown before that in the short term COAMPS forecasts similar to these used in during the field phase of MJO, coupling with the ocean increases convection and wind stress on the equator and on the leading edge of Kelvin wave embedded in MJO. Extended simulations of MJO in slightly different configuration (Fig. 3) show that the rapid development of MJO related to interaction of Kelvin wave and MRG-type disturbance is well represented in the high resolution (15km) COAMPS both in the coupled and uncoupled forecasts, even though the development occurs with about 2 day delay compared to the observations and only the coupled simulation shows the dependence of precipitation on the diurnal variability of SST. The coupled simulations exhibits slightly better precipitation patterns, especially near Sumatra, but at this time scale (up to 2 weeks) the MJO development and propagation appear to depend mostly on atmospheric dynamics, with SST variability contributing to slight shifting of convection.

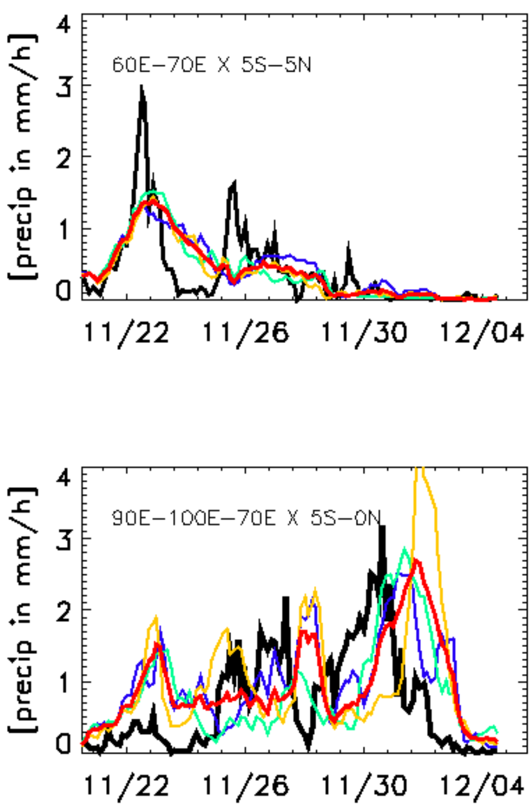

Figure 3. The comparison of the precipitation in the areas of the large MJO precipitation variability for TRMM (black lines), uncoupled simulation (orange lines), and two coupled forecasts with 1m and 2 m resolution at the highest ocean level (blue and green respectively). The red line shows the mean of 3 simulations. All simulations show realistic precipitation magnitudes, although about 2 day delay in MJO development relatively to observations can be observed. The uncoupled simulation overestimates the precipitation near the Maritime Continent.

An interesting feature can be observed in simulations with coarser resolution. In the uncoupled simulation the MJO shows similar propagation characteristics to the finer resolution forecasts but in the coupled simulation Kelvin waves are blocked by vorticity intrusion related to overestimating the MRG strength. In this case the MRG is triggered over the Sumatra mountains and enhanced by the air-sea interaction leading to larger errors in the coupled model. Although the MRG developing in this simulation was too strong, the experiments suggest that this may be one of the processes by which the Maritime Continent can contribute to MJO blocking. In this mechanism Kelvin waves are not directly blocked by the Sumatra topography but by MRG-like lee cyclonic vortices at the tips of Sumatra.

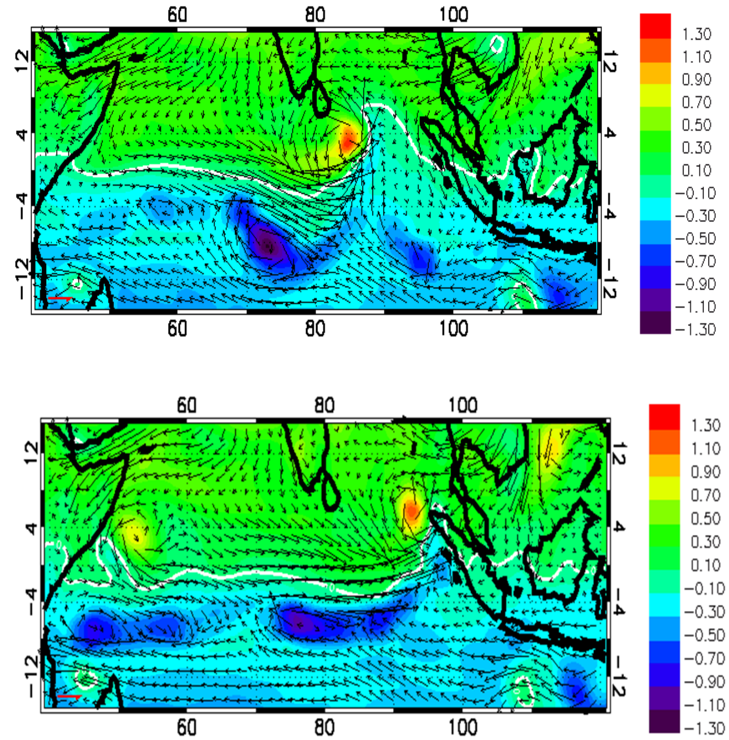

Figure 4 . The absolute vorticity and zonal wind at 850mb, on November 29th 2011. The upper figure shows the results of the coupled forecast in which the Kelvin wave is blocked by the cross equatorial vorticity advection in the strong MRG; the lower panels shows the results of the uncoupled simulation in which MRG did not develop. The examination of the development of the MRG circulation suggests a source of cyclonic vorticity at the northern tip of Sumatra and the strengthening of the wave due to the diurnal SST warming

The investigation of properties of Kelvin waves based on TRMM observations shown in Figure 5 (collaboration with Dariusz Baranowski and Piotr Flatau) indicates that the decrease of amplitude of waves that do not propagate over the Maritime continent occurs west of 80E that would agree with our hypothesis of blocking of the Kelvin wave/MJO by wave interactions, and not just by the presence of land itself.

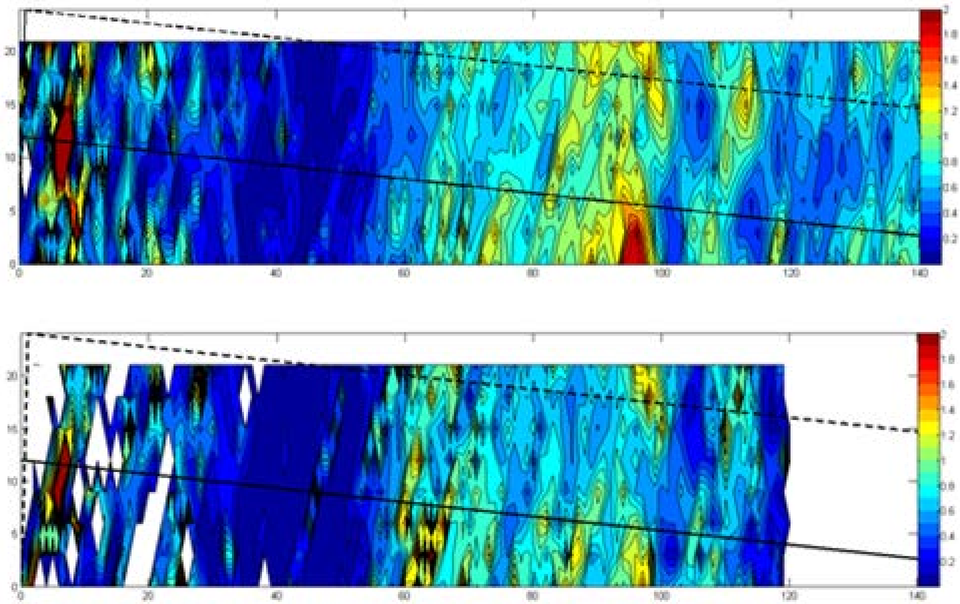

Figure 5: Equatorial precipitation composite as a function of latitude and GTS time, along the Kelvin wave trajectories passing (upper panel) or not passing (lower panel) through the Maritime Continent. The waves appear to be blocked at the certain distance from Maritime Continent (close to 80 E). The "passing" waves exhibit more afternoon precipitation. The solid black line indicates the local noon, the dashed line indicates the local midnight

The influence of Kelvin waves on diurnal SST variability

We investigated the role of convectively coupled Kelvin waves in modyfying the upper ocean variability using the wam layer model (Matthews at al, 2014) that was developed partially under another PI (Piotr Flatau) funded LASP DRI project in collaboration with Adrian Matthews. The analysis of 15 years of TRMM data combined with the ocean warm layer model and atmospheric flux data indicates that for both active and supressed MJO phase Klevin waves induce longitude dependent, rapid supression of diurnal SST warming. The Kelvin wave effect on diurnal SST appears to be strongest in the eastern Indian Ocean and almost disappears in the eastern part of IO.

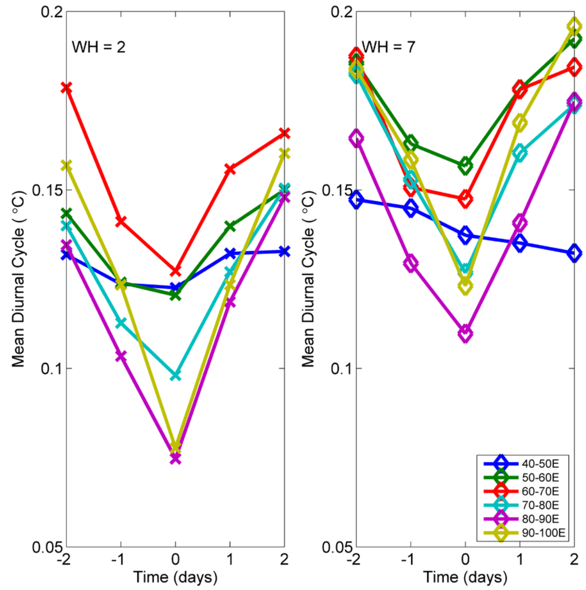

Figure 6 a) Composite of the changes of the diurnal SST variability caused by the passage of the Kelvin wave diring a) active phase of the MJO (RMM index phase 2); b) suppressed phase of the MJO (RMM index phase 7) from Baranowski at al (2014)

Extended DYNAMO run

The simulation using COAMPS during DYNAMO was repeated and extended so the new run covers the period from October 1, 2011 through March 2012. The new run also has 60 vertical levels in the atmosphere versus 40 levels for the previous run. In the new run, the turbulent kinetic energy, turbulent length scale, eddy viscosity and eddy diffusion were save at all depths (Fig. 7). This allows us to include the analysis of vertical mixing when the equatorial jets are formed.

IMPACT/APPLICATIONS

The project contributes to the better understanding of feedbacks between convection and atmospheric and oceanic mixed layer as well as the role of the large scale equatorially trapped waves in atmosphere and the ocean in triggering and maintaining the MJO. The knowledge gained in this project allows us to formulate and test more accurate parameterizations, and to improve the forecasting capability of COAMPS® and NAVGEM – especially the NAVGEM coupled to HYCOM.

For the DYNAMO field campaign, the model results helped to integrate and explain the point observations and to combine them into a coherent description of MJO initiation.

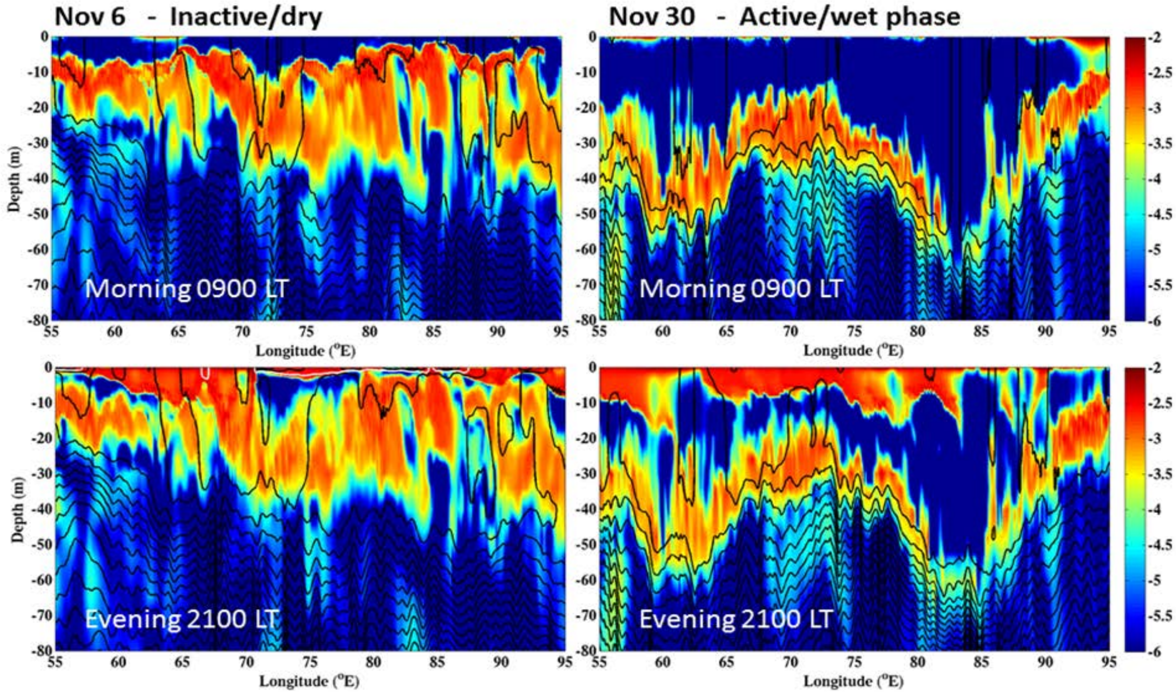

Figure 7 Eddy viscosity along the equator during the dry phase with light winds and a shallow mixed layer in the morning when diurnal heating starts (left, top) and during the evening when convection starts (left, bottom). There is shear in the mixed layer during this time keeping the eddy viscosity large in the upper ocean. During the active phase (right), winds deepen the mixed layer. Shear is confined to the base of the mixed layer. There is still high eddy viscosity at night (right, bottom), but since the mixed layer already is deep, the mixing does not reach the thermocline (From Jensen et al, 2014b).

TRANSITIONS

The improvements to coupled COAMPS® that will result from this work and can be transitioned other, related 6.2 COAMPS projects. In addition the knowledge gain in this project will contribute to better understanding and forecasting of MJO simulation in the Navy global models (NAVGEM and NAVHEM/HYCOM coupled model.

RELATED PROJECTS

This project is a part of the ONR Air-Sea interaction DRI and we collaborate with other PIs involved in this initiative as well as with the wide, international group of researchers involved in DYNAMO/CINDY experiment. MJO development problems are also addressed in ONR-DRI 6.1-SeasnGBL and ONR Coupled COAMPS Extended Range MJO Prediction project, 6.2 MJO prediction project and ESPC global coupled forecasting efforts.

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2014: Jensen, T. G.: Monsoon-Driven Ocean Response in the Northern Indian Ocean. Invited lecture, Environmental Fluid Dynamics Laboratory, Univ. of Notre Dame, IN. Sep 16, 2014

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